National Semiconductor

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LM3595
Parallel White-LED Driver

General Description

The LM3595 is a parallel white-LED driver that is capable of driving four white LEDs. It can supply a total output current of 100mA over an input voltage range of 3.0V to 5.5V. The amount of constant current sourced to the outputs is user selectable using one external sense resistor.

LM3595 typically draws 0.03µA when placed in shutdown, and 200µA when operating in the no-load condition. If any of the outputs are not used, leave the pin(s) unconnected.

Brightness can be controlled by both analog and PWM techniques. A voltage between 0V and 3V may be applied to the BRGT pin to vary the current. Output current will linearly track the voltage applied to the BRGT pin. An active-low level must be present on the BR-ON pin for analog brightness control to be disabled. Alternatively, a PWM signal can be applied to the EN pin to vary the perceived brightness of the LED.

The LM3595 uses an active-high enable level. The LM3595 is available in National's LLP-10 package.

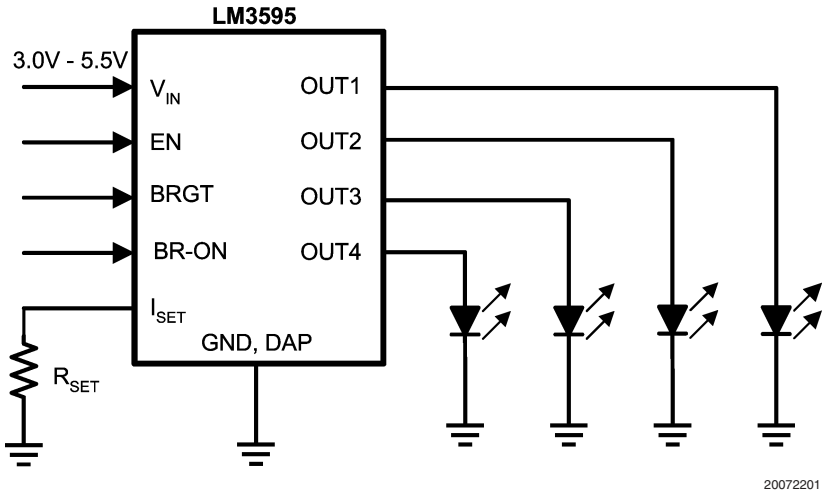
Features

- Regulated I_{OUT} with ± 0.5% matching between constant current outputs
- Drives one, two, three or four white LED's with no bias resistors
- 3.0V to 5.5V Input voltage
- Up to 100mA output current
- Active-High Enable Pin
- Analog Brightness Control
- Very small solution size
- LLP-10 package: 3.0mm x 3.0mm x 0.8mm
- Very Low Shutdown current (0.03µA typ.)

Applications

- Portable devices using white or blue LEDs with display and backlight or frontlight
- Keypad LEDs
- Strobe LEDs

Typical Application Circuit



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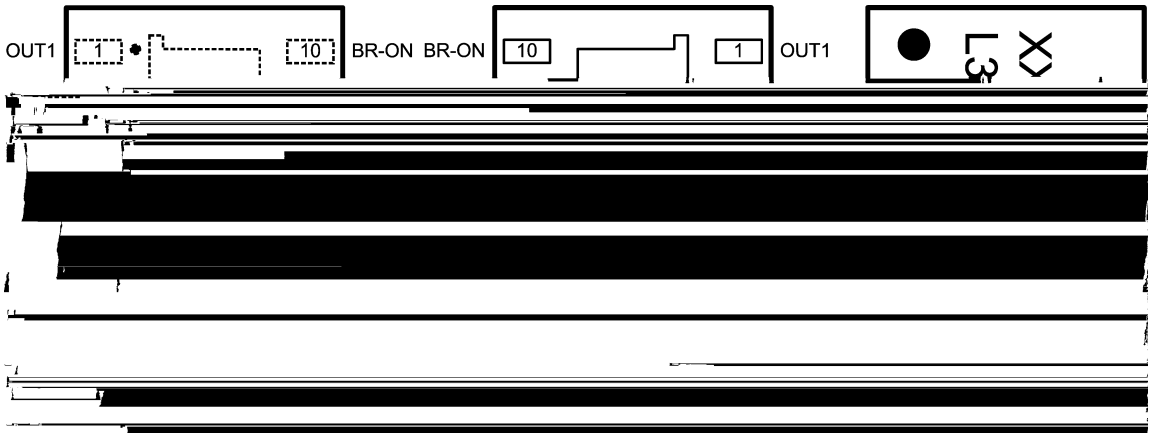
Connection Diagram

LM3595
10-Pin Leadless Leadframe Package (LLP) - 3mm X 3mm
NS Package Number LDA10A



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Pin Description

Pin	Name	Description
9	V_{IN}	Input Voltage
1,2,3,4	OUT1-4	Current Source Outputs 1- 4 - Connect directly to LED's
5	I_{SET}	Current Set Input- The resistor value tied between this pin and ground sets the output current.
6	EN	Active-High Enable Input - A 1MΩ resistor is connected internally between this pin and GND to pull the voltage on this pin to 0V, and shut down the part, when the pin is left floating.
10	BR-ON	Active-High Analog Brightness Control Enable - A voltage of .65 x V_{IN} must be applied to this pin to enable analog brightness control.
7	BRGT	Analog-voltage-controlled Brightness Input - When the BR-ON pin is set high, the voltage on this pin allows analog control of the LED's brightness. The recommended voltage range on this pin is 0 - 3 V where 3V is $V_{BR(MAX)}$. The input impedance of this pin is 300kΩ.
8, DAP	GND	Ground

Ordering Information

Order Number	Package Number	Package Marking	Supplied as:
LM3595LD	LDA10A	L3595	1000 units on Tape-and-Reel
LM3595LDX	LDA10A	L3595	3500 units on Tape-and-Reel

Absolute Maximum Ratings (Notes 1, 2)

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/ Distributors for availability and specifications.

V_{IN}	–0.3V to 6.0V
EN, BR-ON, BRGT	-0.3V to (V_{IN}+ 0.3V) w/ 6.0V max
Junction Temperature ($T_{J-MAX-ABS}$)	150˚C
Continuous Power Dissiation (Note 3)	Internally Limited
Storage Temperature Range	-65˚C to 150˚C
Lead Temperature (Soldering, 5 Sec.)	260˚C
ESD Rating (Note 4)	
Human-body model	2 kV
Machine model	200V

Operating Ratings (Notes 1, 2)

Input Voltage Range (Note 5)	3.0V to 5.5V
Output Voltage Range (Note 5)	2.0V to 5.5V
Junction Temperature Range (Note 6)	-40˚C to 105˚C
Ambient Temperature Range (Note 6)	-40˚C to 85˚C

Thermal Information

Junction-to-Ambient Thermal Resistance, LLP-10 Package (θ_{JA}) (Note 7)	55˚C/W

Electrical Characteristics (Notes 2, 8)

Limits in standard typeface and typical values apply for T_J = 25°C. Limits in **boldface** type apply over the operating junction temperature range. Unless otherwise specified: V_{IN} = 5V, V_{OUTX} = 3.6V, R_{SET} = 8.25kΩ, V(EN) = V_{IN}, V(BR-ON) = 0V

Symbol	Parameter	Conditions	Min	Typ	Max	Units
I_{OUTX}	Output Current Regulation (Note 5)	3.0V ≤ V_{IN} ≤ 5.5V 2.0V ≤ V_{OUTX} ≤ (V_{IN} - 0.7V) R_{SET} = 4.99kΩ	**22.54 (-8%)**	24.5	**26.46 (+8%)**	mA (%)
		3.0V ≤ V_{IN} ≤ 5.5V 2.0V ≤ V_{OUTX} ≤ (V_{IN} - 0.42V) R_{SET} = 8.25kΩ	**13.80 (-8%)**	15.0	**16.20 (+8%)**	
		3.0V ≤ V_{IN} ≤ 5.5V 2.0V ≤ V_{OUTX} ≤ (V_{IN} - 0.28V) R_{SET} = 12.4kΩ	**9.20 (-8%)**	10.0	**10.80 (+8%)**	
$I_{OUTX-BRGT}$	Analog Brightness Control Current Regulation	V(BRGT) = 3.0V, V(BR-ON) = V_{IN}	**13.83 (-6.5%)**	14.8	**15.77 (+6.5%)**	mA (%)
		V(BRGT) = 0V, V(BR-ON) = V_{IN}		100	**250**	µA
$I_{OUT-MATCH}$	Current Matching Between Any Two Outputs			0.5	**4**	%
V_{SET}	I_{SET} Pin Voltage		**1.147 (-6%)**	1.22	**1.293 (+6%)**	V (%)
I_{OUTX}/I_{SET}	Output Current to Current Set Ratio		**95 (-5%)**	100	**105 (+5%)**	
V_{HR}	Current Source Headroom Voltage (Note 5)	I_{OUT} = 95% x I_{OUT}(nom) R_{SET} = 4.99kΩ (I_{OUT}(nom) approx. 25mA)		500	**690**	mV
		I_{OUT} = 95% x I_{OUT}(nom) R_{SET} = 12.4kΩ (I_{OUT}(nom) approx. 10mA)		200	**280**	
I_Q	Quiescent Supply Current	I_{OUTX} = 0mA, V(BR-ON) = V_{IN}, R_{SET} = Open		200	**300**	µA
		I_{OUTX} = 0mA, V(BR-ON) = V_{IN}, R_{SET} = 8.25kΩ		350		
I_{SD}	Shutdown Supply Current	EN = 0, V(BR-ON) = V_{IN}		0.03	**1**	µA
V_{EN-IH}	EN Input Logic High	3.0V ≤ V_{IN} ≤ 5.5V	**1.2**		V_{IN}	V
V_{EN-IL}	EN Input Logic Low	3.0V ≤ V_{IN} ≤ 5.5V	0		**.5**	V
$V_{BRON-IH}$	BR-ON Input Logic High	3.0V ≤ V_{IN} ≤ 5.5V	**.65 x V_{IN}**		V_{IN}	V
$V_{BRON-IL}$	BR-ON Input Logic Low	3.0V ≤ V_{IN} ≤ 5.5V	0		**.35 x V_{IN}**	V

Electrical Characteristics (Notes 2, 8) (Continued)

Limits in standard typeface and typical values apply for T_J = 25°C. Limits in **boldface** type apply over the operating junction temperature range. Unless otherwise specified: V_{IN} = 5V, V_{OUTX} = 3.6V, R_{SET} = 8.25kΩ, V(EN) = V_{IN}, V(BR-ON) = 0V

Symbol	Parameter	Conditions	Min	Typ	Max	Units
I_{EN}	EN Pin Current (Note 9)	V(EN) = 1.5V		1.5		µA
		V(EN) = 0V		0		
I_{BR-ON}	BR-ON Pin Current	$0 \le V_{BR-ON} \le V_{IN}$		0		µA

Note 1: Absolute Maximum Ratings indicate limits beyond which damage to the component may occur. Operating Ratings are conditions under which operation of the device is guaranteed. Operating Ratings do not imply guaranteed performance limits. For guaranteed performance limits and associated test conditions, see the Electrical Characteristics tables.

Note 2: All voltages are with respect to the potential at the GND pin.

Note 3: Thermal shutdown circuitry protects the device from permanent damage.

Note 4: The Human body model is a 100pF capacitor discharged through a 1.5kΩ resistor into each pin. The machine model is a 200pF capacitor discharged directly into each pin. MIL-STD-883 3015.7

Note 5: The operation rating for minimum input voltage, V_{MIN}, is limited by V_{OUTX} and I_{OUTX} as dictated by headroom voltage. The equation, $V_{MIN} \ge (V_{OUTX}+V_{HR})$, must be satisfied for the desired output current to be realized. For more information, see the section on Output Current Capability found in this datasheet.

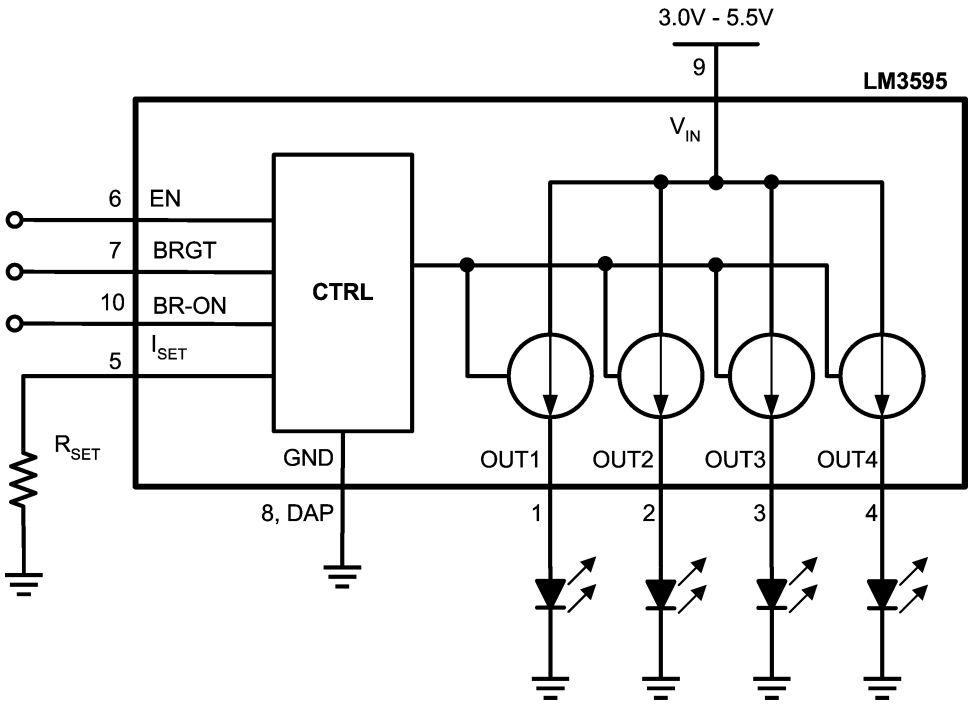
Note 6: In applications where high power dissipation and/or poor package thermal resistance is present, the maximum ambient temperature may have to be derated. Maximum ambient temperature (T_{A-MAX}) is dependent on the maximum operating junction temperature ($T_{J-MAX-OP}$ = 105°C), the maximum power dissipation of the device in the application (P_{D-MAX}), and the junction-to ambient thermal resistance of the part/package in the application (θ_{JA}), as given by the following equation: $T_{A-MAX} = T_{J-MAX-OP} - (\theta_{JA} \times P_{D-MAX})$.

Note 7: Junction-to-ambient thermal resistance (θ_{JA}) is taken from a thermal modeling result, performed under the conditions and guidelines set forth in the JEDEC standard JESD51-7. The test board is a 4-layer FR-4 board measuring 102mm x 76mm x 1.6mm with a 2x1 array of thermal vias. The ground plane on the board is 50mm x 50mm. Thickness of copper layers are 36µm/18µm/18µm/36µm (1.5oz/1oz/1oz/1.5oz). Ambient temperature in simulation is 22°C, still air. Power dissipation is 1W. The value of θ_{JA} of the LM3595 in LLP-10 could fall in a range as wide as 50°C/W to 150°C/W (if not wider), depending on PWB material, layout, and environmental conditions. In applications where high maximum power dissipation exists (high V_{IN}, high I_{OUT}), special care must be paid to thermal dissipation issues. For more information on these topics, please refer to Application Note 1187: Leadless Leadframe Package (LLP) and the Power Dissipation and PCB Layout Considerations sections of this datasheet.

Note 8: All room temperature limits are 100% tested or guaranteed through statistical analysis. All limits at temperature extremes are guaranteed by correlation using standard Statistical Quality Control methods (SQC). All limits are used to calculate Average Outgoing Quality Level (AOQL). Typical numbers are not guaranteed, but do represent the most likely norm.

Note 9: The EN pin has an internally connected 1MΩ pull-down resistor

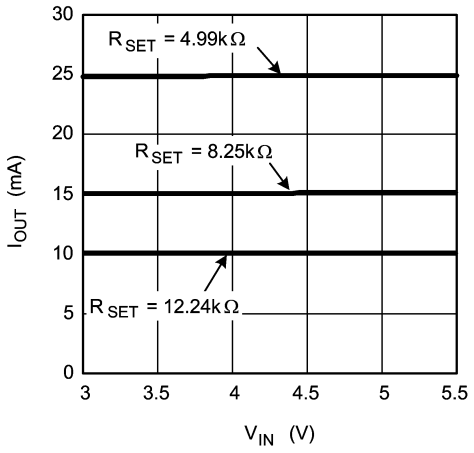
Block Diagram



Typical Performance Characteristics

Unless otherwise specified: V_{IN} = 5V, BR-ON = 0V, R_{SET} = 8.25kΩ, EN = V_{IN}, T_A = 25˚C

Output Current vs. Input Voltage



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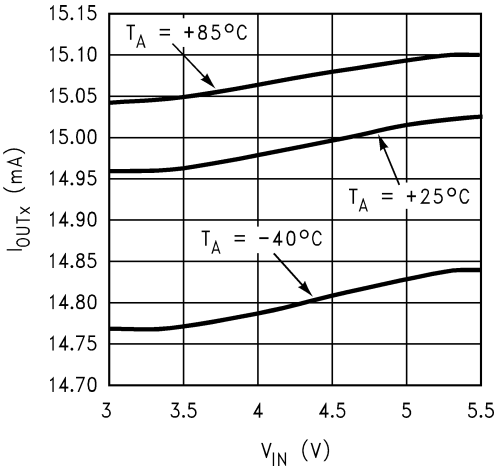
Output Current vs. Input Voltage



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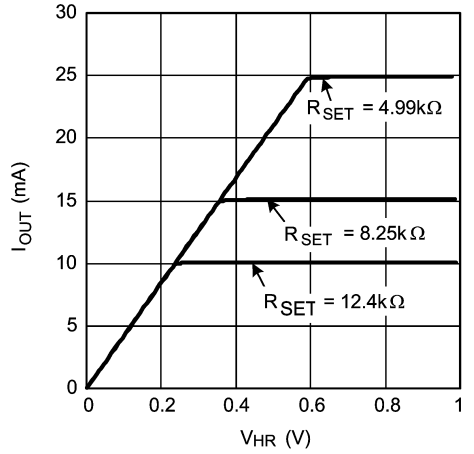
Output Current vs. Headroom Voltage



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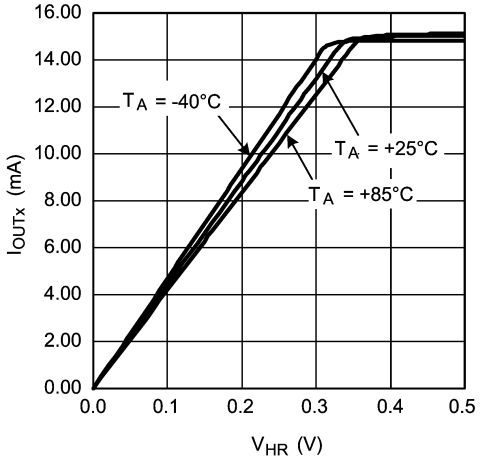
Output Current vs. Headroom Voltage



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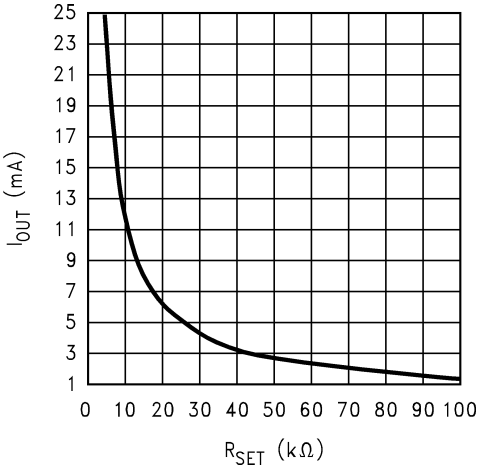
Output Current vs. Current Set Resistor



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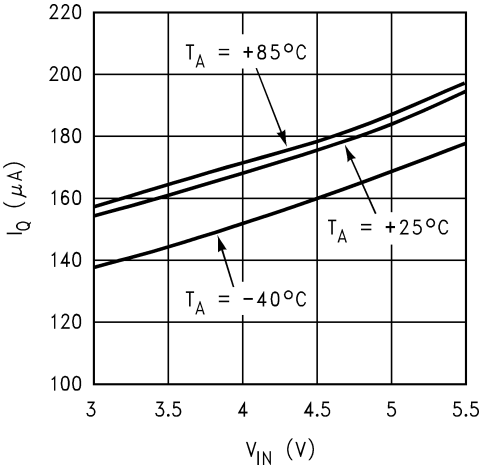
Quiescent Current vs. Input Voltage (R_{SET} = Open)



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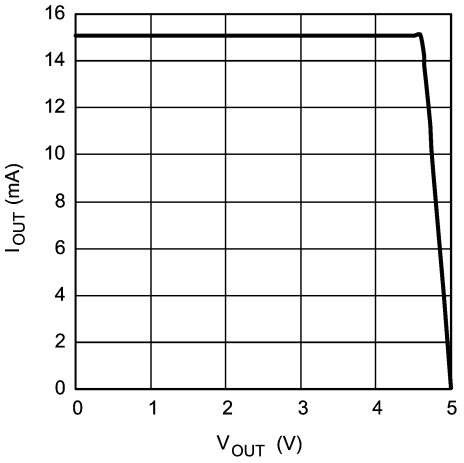
Typical Performance Characteristics

Unless otherwise specified: V_{IN} = 5V, BR-ON = 0V, R_{SET} = 8.25kΩ, EN = V_{IN}, T_A = 25˚C (Continued)

Output Current vs. Output Voltage



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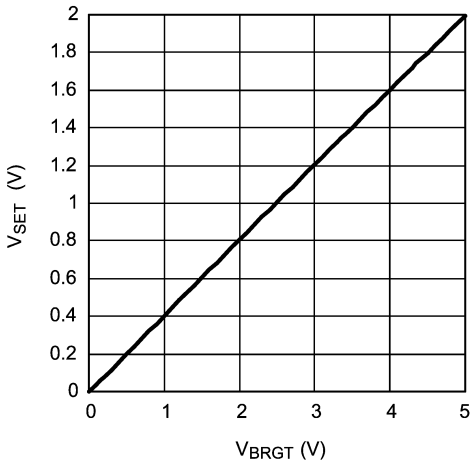
I_{SET} Pin Voltage vs. BRGT Pin Voltage



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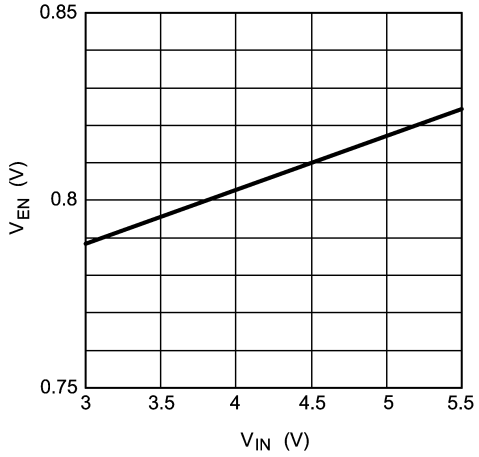
Enable Voltage vs. Input Voltage



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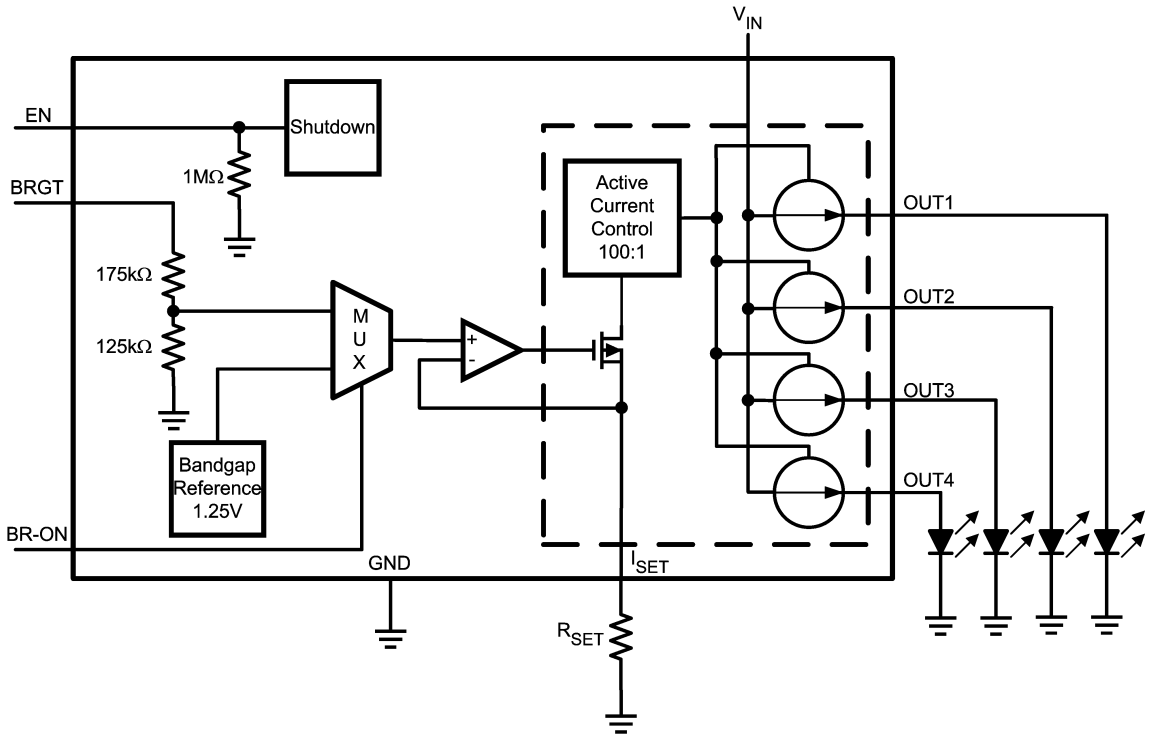
Detailed Block Diagram



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Circuit Description

The LM3595 is a parallel white-LED driver with four matched current outputs. This part is intended to be driven off of an existing power supply rail or other regulated voltage source found within the surrounding system. The matched current regulators each have a 100:1 current ratio between the OUTx outputs and the I_{SET} currents. The mirrors control the current through the LEDs without the use of external ballast resistors. With a total of 100mA of total output current available, the LM3595 is easily capable of supplying 25mA per each of the four outputs through the proper selection of the R_{SET} resistor. LED brightness control can be achieved on the LM3595 with a PWM signal and/or an analog voltage.

Application Information

ENABLE / SHUTDOWN

When the voltage on the active-high-logic enable pin is low, the LM3595 will be in shutdown. While disabled, the LM3595 typically draws 0.1µA. When the EN pin is unconnected, the part automatically goes into shutdown due to an internal 1MΩ pull-down resistor that is tied between EN and GND.

OUTPUT CURRENT CAPABILITY

The LM3595 is capable of providing up to 25mA of current to each of the four outputs given an input voltage of 3.0V to 5.5V. The outputs have a typical current matching of 0.5% between adjacent sources. An external resistor can be used to set the output current, as approximated with the following the equation:

$$R_{SET}=100 \text{ x } (1.22V / I_{OUTX}) \text{ with BR-ON = 0V}$$

In order for the output currents to be regulated properly, sufficient headroom voltage (V_{HR}) must be present. The headroom voltage refers to the minimum amount of voltage that must be present across the current source in order to ensure the desired current is realizable. To ensure the desired current is obtained, apply the following equations to find the minimum input voltage required:

$$V_{IN} - V_{OUTX} \geq V_{HR}$$

V_{OUTX} is the diode forward voltage, and V_{HR} is defined by the following equation:

$$V_{HR} = k_{HR} \text{ x } (0.95 \text{ x } I_{OUTX})$$

I_{OUTX} is the desired diode current, and k_{HR}, typically 23mV/mA in the LM3595, is a proportionality constant that represents the ON-resistance of the internal current mirror transistors. For worst-case design calculations, using a k_{HR} of 30mV/mA is recommended. (Worst-case recommendation accounts for parameter shifts from part-to-part variation and applies over the full operating temperature range). Changes in headroom voltage from one output to the next, possible with LED forward voltage mismatch, will result in different output currents and LED brightness mismatch. Thus, operating the LM3595 with insufficient headroom voltage across all current sources should be avoided.

TABLE 1. I_{OUT}, R_{SET} and V_{HR-MIN} Voltage (BR-ON = 0V), k_{HR}= 30 mV/mA (worst-case)

I_{OUT}	R_{SET}	$V_{HEADROOM}$
10mA	12.4kΩ	285mV
15mA	8.25kΩ	430mV
25mA	4.88kΩ	715mV

PWM BRIGHTNESS CONTROL

Brightness control can be implemented by pulsing a signal at the EN pin. When a PWM signal is used to drive the EN pin of the LM3595, the BR-ON pin should be driven low. The R_{SET} value should be selected using the R_{SET} equation when the analog brightness control feature is disabled. LED brightness is proportional to the duty cycle (D) of the PWM signal. For linear brightness control over the full duty cycle adjustment range, the PWM frequency (f) should be limited to accommodate the turn-on time (T_{ON} = 50µs) of the device.

$$D \text{ x } (1/f) > T_{ON}$$

$$f_{MAX} = D_{MIN} \div T_{ON}$$

If the PWM frequency is much less than 100Hz, flicker may be seen in the LEDs. For the LM3595, zero duty cycle will turn off the LEDs and a 50% duty cycle will result in an average I_{OUT} being half of the programmed LED current. For example, if R_{SET} is set to program 15mA, a 50% duty cycle will result in an average I_{LED} of 7.5mA. I_{OUT} being half the programmed LED current. R_{SET} should be chosen not to exceed the maximum current delivery capability of the device.

ANALOG BRIGHTNESS CONTROL

The LM3595 allows for analog brightness control using the BR-ON, and BRGT pin. To enable this function, the BR-ON pin must be set to a voltage greater or equal to $0.45*V_{IN}$. With analog brightness enabled, the voltage delivered to pin BRGT can be used to adjust the output currents. Use the maximum desired current ($I_{OUTX(max)}$) and the maximum analog voltage to be used in the adjustment ($V(BR)_{(max)}$) to size R_{SET} according to the following equation:

$$R_{SET} = 100 \times \left(\frac{1.22\,V}{I_{OUTx\,(max)}} \right) \times \left(\frac{V(BRGT)_{(max)}}{3.0\,V} \right)$$

Table 2 shows the current through each LED for the LM3595 with various BRGT and RSET values.

When analog brightness is used, applying 0V to the BRGT pin does not turn the LEDs off completely. There is a small amount of leakage current (100µA) that typically causes a small amount of light to be emitted from the LED. In order to completely turn off the LEDs, drive the EN pin low to disable the part.

Application Information (Continued)

TABLE 2. LED Current when using the BRGT input with BR-ON = V_{IN}

R_{SET} (Ω)	4.99kΩ	6.25kΩ	8.25kΩ	12.4kΩ
VBRGT(V)	I_{LED}(mA)	I_{LED}(mA)	I_{LED}(mA)	I_{LED}(mA)
0.0	0.1	0.1	0.1	0.1
0.5	4.1	3.3	2.5	1.6
1.0	8.1	6.7	4.9	3.3
1.5	12.2	10.0	7.4	4.9
2.0	16.3	13.3	9.9	6.6
2.5	20.4	16.7	12.3	8.2
3.0	24.5	20.0	14.8	9.8

LED SELECTION

The LM3595 is designed to drive white-LEDs with a typical forward voltage of 3.0V to 4.0V. The maximum LED forward voltage that the LM3595 can accommodate is highly dependant upon V_{IN} and I_{OUTX}. (See the section on Output Current Capability for more information on finding maximum V_{OUTX}.) For applications that demand color and brightness matching, care must be taken to select LEDs from the same chromaticity group. Forward current matching is assured over the LED process variations due to the constant current outputs of the LM3595.

TABLE 3. White LED Selection: Component Manufacture Contact

Manufacturer	Contact
Osram	www.osram-os.com
Nichia	www.nichia.com

PARALLEL OUTx OUTPUTS FOR INCREASED CURRENT DRIVE

Outputs OUT1 through OUT4 may be connected together in any combination to drive higher currents through fewer LEDs. For example in *Figure 1*, outputs OUT1 and OUT2 are connected together to drive one LED while OUT3 and OUT4 are connected together to drive a second LED.

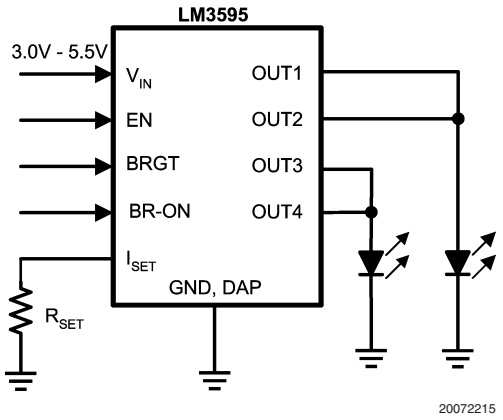


FIGURE 1. Two Parallel Connected LEDs

With this configuration, two parallel current sources of equal value provide current to each LED. R_{SET} and V_{BRGT} should therefore be chosen so that the current through each output is programmed to 50% of the desired current through the parallel connected LEDs. For example, if 30mA is the desired drive current for 2 parallel connected LEDs, R_{SET} and V_{BRGT}should be selected so that the current through each of the outputs is 15mA. Other combinations of parallel outputs may be implemented in similar fashions, such as in *Figure 2*.

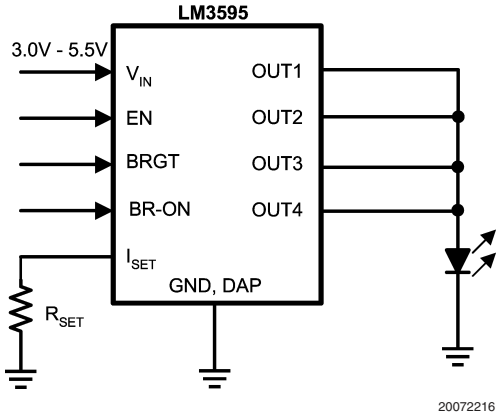


FIGURE 2. One Parallel Connected LED

Connecting outputs in parallel does not affect internal operation of the LM3595 and has no impact on the Electrical Characteristics and limits previously presented. The available diode output current, maximum diode voltage, and all other specifications provided in the Electrical Characteristics table apply to parallel output configurations, just as they do to the standard 4-LED application circuit.

POWER DISSIPATION

The maximum allowable power dissipation that this package is capable of handling can be determined as follows:

$$P_{DMax} = (T_{JMax} - T_A) / \theta_{JA}$$

Where T_{JMAX} is the maximum junction temperature, T_A is the ambient temperature, and θ_{JA} is the junction-to-ambient thermal resistance of the specified package. The LM3595 come in the LLP-10 package that has a junction-to-ambient thermal resistance (θ_{JA}) equal to 55˚C/W. This value of θ_{JA} is highly dependant upon the layout of the PC board (See the PCB Layout Considerations section of this datasheet for more information). The actual power dissipated by the LM3595 follows the equation:

$$P_{DISS}=(V_{IN}x\ I_{IN}) - N(V_{OUTX}\ x\ I_{OUTX})$$

Where N equals the number of active outputs, V_{OUTX} is the LED forward voltage, and I_{OUTX} is the current supplied to the

Application Information (Continued)

diode by the LM3595. Power dissipation must be less than that allowed by the package. Please refer to the Absolute Maximum Rating of the LM3595.

INPUT CAPACITOR SELECTION

The LM3595 is designed to run off of a fixed input voltage. Depending on the stability and condition of this voltage rail, it may be necessary to add a small input capacitor to help filter out any noise that may be present on the line. In the event that filtering is needed, surface-mount multi-layer ceramic capacitors are recommended. These capacitors are small and inexpensive. A capacitance of 1µF is typically sufficient.

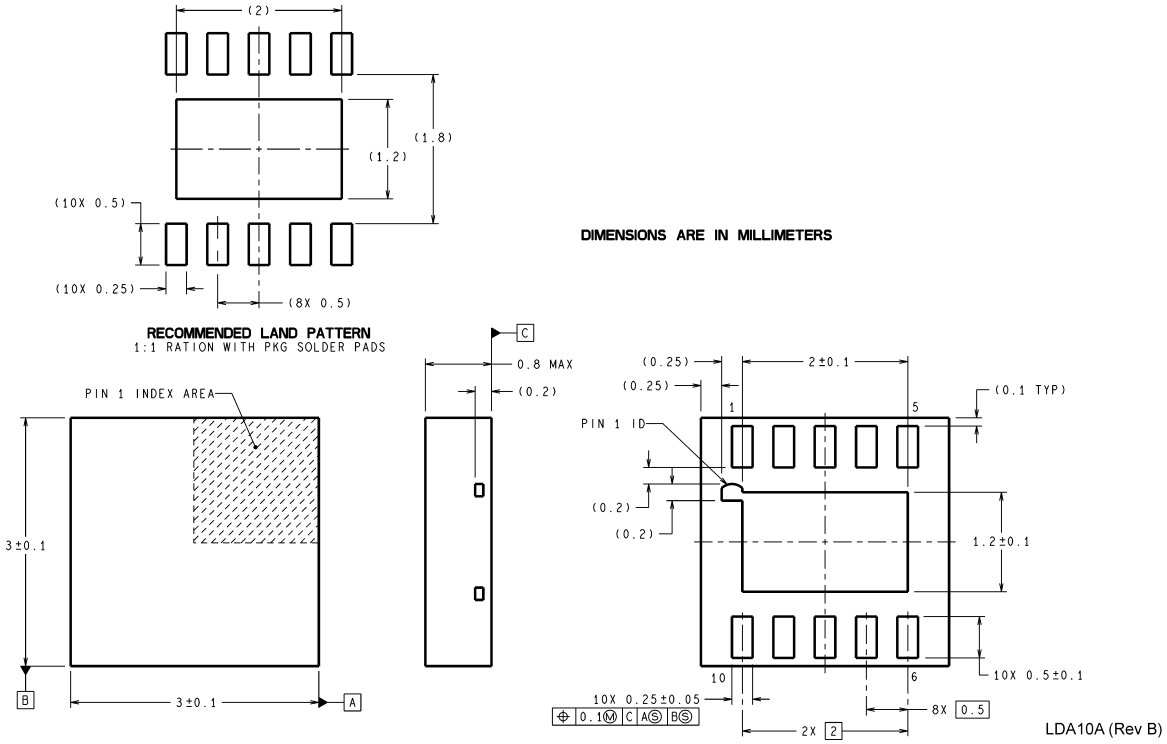
THERMAL PROTECTION

The LM3595 has internal thermal protection circuitry to disable the part if the junction temperature exceeds 150˚C. This feature will protect the device from damage due to excessive power dissipation. The device will recover and operate normally when the junction temperature falls below the maximum operating junction temperature of 105˚C. It is important to have good thermal conduction with a proper layout to reduce thermal resistance.

PCB LAYOUT CONSIDERATIONS

The LLP is a leadframe based Chip Scale Package (CSP) with very good thermal properties. This package has an exposed DAP (die attach pad) at the center of the package measuring 2.0mm x 1.2mm. The main advantage of this exposed DAP is to offer lower thermal resistance when it is soldered to the thermal land on the PCB. For PCB layout, National highly recommends a 1:1 ratio between the package and the PCB thermal land. To further enhance thermal conductivity, the PCB thermal land may include vias to a ground plane. For more detailed instructions on mounting LLP packages, please refer to National Semiconductor Application Note AN-1187.

Physical Dimensions inches (millimeters) unless otherwise noted



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2. A critical component is any component of a life support device or system whose failure to perform can be reasonably expected to cause the failure of the life support device or system, or to affect its safety or effectiveness.

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